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A ^3He REFRIGERATOR MODULE

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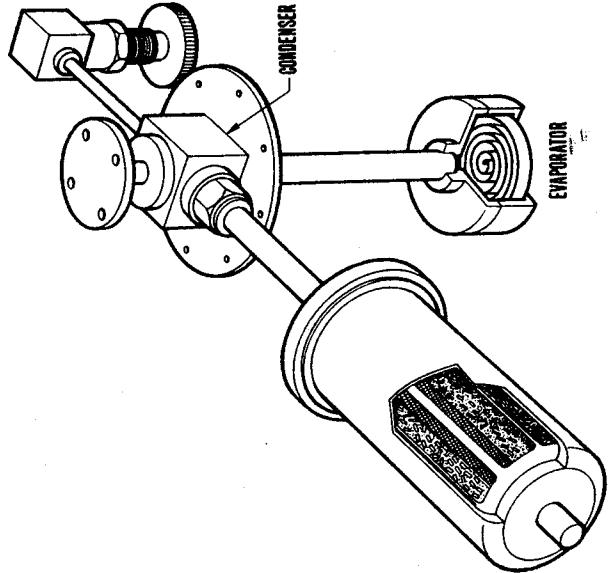
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We have developed a ^3He refrigerator module which allows the temperature range of a coldplate-style helium dewar to be extended without costly and time-consuming dewar modification. The module bolts to the coldplate and is controlled by a single heater. The module has reached 0.27 K.

We have built a ^3He refrigerator module that has several unique features. It is a self-contained, demountable ^3He refrigerator. When the unit is needed, it can be taken off the shelf and bolted to the coldplate of a superfluid helium dewar. Similarly, when it is not needed, the module can be easily removed and stored for later use. This feature has greatly increased the versatility of our coldplate-style dewar. This versatility was achieved without costly or time-consuming modification of the dewar. The module has extended the temperature range of our dewar to 0.27 K. After the initial filling with ^3He , it can be operated or stored indefinitely. The operation of the module is controlled by a single heater. This has allowed the operation to be easily automated.

The module is shown in Figure 1. The specifications are listed in Table I. The refrigerator uses an adsorption pump filled with Linde 5A zeolite. Activated charcoal could also be used. There is a finned copper structure inside the pump to improve the thermal conductivity of the adsorber. The control heater is attached to the copper. A copper wire connects the pump to the coldplate. This wire is sized to cool the pump from 30 K to 20 K in 10 min when the coldplate is at 2 K. The condenser is a hollow copper block that is bolted to the coldplate. To improve the thermal conductance of this joint,

Besides increasing our dewar's versatility, we had another motive in using a modular design. We are interested in building a 3He refrigerator for use in space. By building this unit we could experiment with a demountable design before we worried about the difficulties caused by zero gravity. There are several reasons for wanting temperatures below 1 K in space. The low-gravity environment allows the critical behavior of fluids to be studied in the absence of gravitational mixing.⁽¹⁾ Of particular interest is the tricritical point in $^3\text{He}/^4\text{He}$ mixtures. This requires temperatures in the region of 0.87 K. Several research groups are now considering doing tricritical point experiments in space. Another use of temperatures below 1 K is to cool high-sensitivity bolometers.^(2,3) Such bolometers can be used for far infrared photometry and spectrometry. The noise equivalent power (NEP) of bolometers improved as T^n where $3/2 < n < 5/2$. A factor of 50 decrease in NEP is possible by going from 1.5 K to 0.3 K. For some bolometer and tricritical point applications, a modular design will be required. For example, in the Shuttle Infrared Telescope Facility (SIRTF), a 1 to 2 K coldplate will probably be provided.⁽⁴⁾ An experimenter needing a lower temperature module would have to provide his own refrigeration



Zeolite mass	118 gm
³ He amount	0.63 moles
³ He pressure at 300 K	6.2 MPa
Pump volume	0.14 l
Initial volume	0.25 l

a thin indium gasket has been inserted between the condenser and the coldplate. Spring washers have been placed under the bolt heads to allow for thermal expansion. The evaporator is a hollow copper block hung from the condenser. A spiral of copper foil has been brazed inside the evaporator to increase the contact area between the liquid ^3He and the evaporator. The unit is charged with ^3He through a valve attached to the condenser. This is a bellows-sealed valve with a metal seat. After filling, the open port of the valve is capped off.

The refrigerator is simple to operate. Starting with the system at 2 K or colder, the heater is turned on. This heats the pump to 30 K, driving out the ^3He . The gas condenses in the condenser and falls into the evaporator. After about 15 min, the temperatures stabilize, and the heater may be turned off. As the pump cools, it reabsorbs the ^3He . This causes evaporative cooling in the evaporator. Refrigeration is produced until all of the liquid is evaporated, at which time the cycle may be restarted. Since the module requires only a single heater to operate, it is trivial to automate the system.

A detailed method of calculating the amount of ^3He required has been given elsewhere.⁽⁵⁾ A simplified method will be presented here. The system is charged, at room temperature, to a density ρ_0 . During condensation the free volume is

$$V_0 = V_p + V_g + V_\ell \quad (1)$$

where V_p is the free volume in the pump, V_g is the volume of the gas in the rest of the system, and V_ℓ is the volume of the condensed liquid. At this time the pressure is uniform but the temperature is not. The pump has been heated to a temperature T_p while the condenser and evaporator are at some lower temperature T . However, by the ideal gas law, the system can be treated as if the temperature were uniform at T and as if the effective volume of the system were

$$V = V_g + V_\ell + V_p(T/T_p) \quad (2)$$

The last term on the right can often be ignored if $V_p < V_g + V_\ell$ and $T \ll T_p$, the usual conditions. Since $V < V_0$, the effective density of ^3He is increased:

$$\rho = \rho_0 V_0 / V \approx \rho_0 [1 + V_p / (V_g + V_\ell)] \quad (3)$$

The condensation process can be described in terms of ρ with aid of the saturated vapor pressure curve (Fig. 2). Consider a gas of density ρ at some temperature greater than its condensation temperature. If this gas is cooled its density will not change because the amount and volume of gas are constant. The system will follow the horizontal line in Figure 2. Condensation will begin at T_ℓ . If cooling

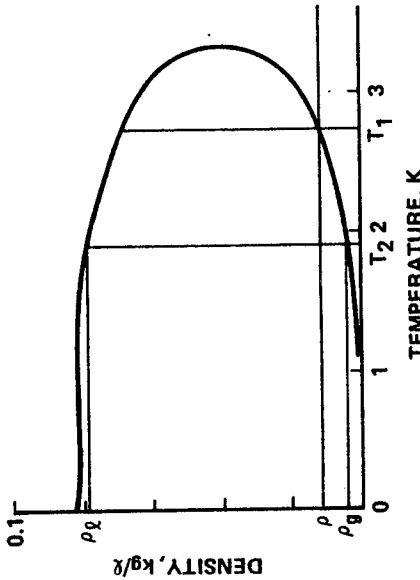


Figure 2 : Liquid-vapor density along the saturated vapor pressure curve (from Ref. 6). The notations are explained in the text.

continues, liquid phase will follow the upper branch of the coexistence curve and the gas phase will follow the lower branch. The average density will not change. This allows V_ℓ to be calculated at some temperature T_2 :

$$V_\ell = V_g (\rho - \rho_g) (\rho_g - \rho)^{-1}, \quad (4)$$

where ρ_g is the density of the gas phase and ρ_g is the density of the liquid phase. Ignoring the last term of Eq. (2), it can be combined with Eq. (4) to give

$$V_\ell = V(\rho - \rho_g)(\rho_g - \rho)^{-1}. \quad (5)$$

The initial charge (needed to produce a volume of liquid at T_2) can be found by combining Eqs. (3) and (5):

$$\rho_0 V_0 = V_g \rho_g + (V - V_\ell) \rho_g \quad (6)$$

Equation (6) is just an expression of the conservation of mass. Ideally, T_2 would be the coldplate temperature.

A time history of the temperatures of various parts of our refrigerator is shown in Figure 3. During the heating part of the cycle there is a sudden dip in the pump temperature as a result of the cooling effect of the helium being desorbed. Using a Germanium resistance thermometer, the lowest temperature that we have measured is 0.27 K. This is limited by the low vapor pressure at that temperature and the pumping speed of the system. The hold time was only 1.5 hr. While this is adequate for our present needs, it is much less than the 12 hr without load, that we had planned on. The problem is the poor thermal conductance between the condenser and the coldplate. During condensation, considerable heat is conducted through the gas and connecting tubing from the pump to the condenser. This heat must pass through the condenser to the coldplate. Because the

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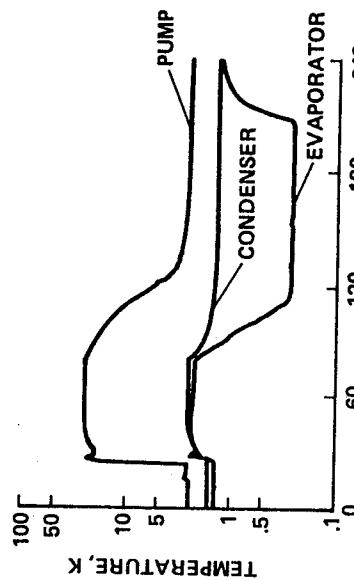


Figure 3 : Time history of the temperatures of various components during a typical cycle

conductance of this last joint is poor, the temperature of the condenser becomes significantly warmer than the coldplate. Thus, the condensation occurring at a temperature greater than the coldplate temperature. So [by Eq. (4)] less helium is condensed. We are currently investigating various means of improving this joint.

In summary, we have developed a ^3He refrigerator that greatly increases the versatility of a coldplate-style superfluid helium dewar. It is a self-contained demountable unit that is controlled by a single heater and can reach 0.27 K.

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